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National Ocean Survey

## A User's Guide to a Computer Program for Harmonic Analysis of Data at Tidal Frequencies

R. E. DENNIS AND E. E. LONG



ROCKVILLE, MD.

July 1971

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NOAA Technical Report NOS 41

**A User's Guide to a Computer Program for  
Harmonic Analysis of Data at  
Tidal Frequencies**

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# A User's Guide to a Computer Program for Harmonic Analysis of Data at Tidal Frequencies

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**ABSTRACT.** This report describes a FORTRAN-IV program for the harmonic analysis of a series of 15 or 29 days of uniformly spaced tidal data (observations). The program is usable with minor modifications on any computer with a 140K memory which accepts FORTRAN input. The mathematical basis and equations for the determination of tidal constants from observational data are given. This report should be used with Manual of Harmonic Analysis and Prediction of Tides, C&GS Special Publication No. 98, Revised (1940) Edition, published in 1941, for reference to formulas and tables.

It was recognized in ancient time that tides follow a relatively regular cycle, recurring periodically. Since any periodic motion or oscillation can be resolved into components consisting of simple harmonic motions, a method for reducing tidal motions to these components was inevitable. Lord Kelvin devised such a method about 1867. His method followed the suggestions and speculations made by Laplace, Young, and Airy during the earlier part of the 19th century, but full credit belongs to Kelvin for making such analysis practical. In the late 19th century and early 20th century, William Ferrel and Rollin A. Harris of the U.S. Coast and Geodetic Survey both made important contributions to harmonic analysis of tides and interpretation of the results.

In 1885, Leland P. Shidy of the U.S. Coast and Geodetic Survey designed a set of stencils for the "Standard Method" of harmonic analysis of observational data (Report of the U.S. Coast and Geodetic Survey, 1893, Vol. 1, p. 108). A stencil with apertures was fitted over tabulations of observed data to obtain sums for computing the harmonic constants of the tidal constituents. Only after this—a process involving computation of values for about 20 coefficients for use in the tide equations—could the tide prediction begin. Operational harmonic analysis was continued by hand until the

presently used computer system was implemented in 1965.

The original version of this program for the standard harmonic analysis of tidal data was completed in 1965. Since then, improvements in the method and refinements in programing have yielded a program that can analyze the observational data for a station in as little as 1.5 seconds on a CDC-6600 computer.

## BASIC HARMONIC EQUATION AND DETERMINATION OF TIDAL CONSTANTS FROM OBSERVATIONAL DATA

For analyzing equally spaced short-period data (15 days or 29 days), this program utilizes the standard Fourier analysis and traditional methods of the former Coast and Geodetic Survey described by Schureman (1941) with extracts from Doodson (1924) and Harris (1897) reports on tidal analysis.

Harmonic analysis of tidal data entails three basic processes:

1. Initial separation of the tidal constituents from the data
2. Orientation of the constituent tides with the astronomical elements
3. Elimination from each constituent sought of effects of other tidal constituents

The equation

$$h = H_0 + \sum_n f_n H_n \cos [a_n t - (\kappa_n - [V_0 + u]_n)] \quad (1)$$

describes the height of tide at any time for which

$H_0$ —mean value of tide for observations

$$H_0 = \frac{1}{N} \sum_{i=0}^{N-1} h_i$$

$t$ —time reckoned from some arbitrary point

$f_n$ —node factor of constituent

$H_n$ —mean amplitude of the constituent

$a_n$ —speed of constituent

$\kappa_n$ —epoch of the constituent at  $t = 0$  for period of observation

$(V_0 + u)_n$ —value of argument of constituent at  $t = 0$  for period of observation

$n$ —any particular constituent being computed

$N$ —total number of data values used in analysis

The factor  $H_n$  is the mean amplitude of constituent,  $n$ , for an entire nodal period, whereas the adjustment using the node factor  $f_n$ , denoted

$$R_n = f_n H_n \quad (2)$$

is the amplitude pertaining to a particular time. The amplitudes  $R_n$  are derived from observational data.

Although the constant  $\kappa_n$  is used ultimately to characterize the constituent, the quantity  $\kappa_n - (V_0 + u)_n$  may be designated

$$\zeta_n = \kappa_n - (V_0 + u)_n \quad (3)$$

where  $\zeta_n$  is derived from the data.  $\zeta_n$  represents the phase of the constituent at  $t = 0$  for a particular series of observations.

To use the tidal equation in harmonic form we follow Schureman's (1941) discussion of the Fourier series technique. The curve described by

$$h = H_0 + C_1 \cos \Theta + C_2 \cos 2\Theta + \dots C_k \cos k\Theta + S_1 \sin \Theta + S_2 \sin 2\Theta + \dots S_l \sin l\Theta \quad (4)$$

will pass through the  $N$  coordinates given by ordinates  $h_0, h_1, h_2, h_3, \dots, h_{N-1}$  and abscissas  $0, \delta, 2\delta,$

$\dots, (N-1)\delta$  where  $N\delta = 2\pi$  provided that

$$C_p = \frac{2}{N} \sum_{i=0}^{N-1} h_i \cos ip\delta \quad (5)$$

and

$$S_p = \frac{2}{N} \sum_{i=0}^{N-1} h_i \sin ip\delta \quad (6)$$

Since the limits of  $k$  and  $l$  are

$$\text{for } N \text{ even, } \begin{cases} \lim k = \frac{N}{2} \\ \lim l = \frac{N}{2} - 1 \end{cases}$$

$$\text{for } N \text{ odd, } \lim k = \lim l = \frac{N-1}{2}$$

the limit of  $p$  is correspondingly always less than  $\frac{N}{2}$ .

When  $\Theta$  represents the constituent day,  $C_1$  and  $S_1$  corresponding to  $p = 1$  represent the diurnal constituents, and  $C_2, S_2$  corresponding to  $p = 2$  represent the semidiurnal constituents. For tidal work values of  $p$  greater than 8 are seldom used, so the limit of  $N/2$  has no significance.

Using the notation

$a$  = speed of constituent sought in degrees per solar hour

$\delta$  = length of sampling period in solar hours

the coefficient equations may be written more exactly for real data:

$$C_p = \frac{2}{N} \sum_{i=1}^N h_i \cos \left[ (i-1) \left( \frac{\pi}{180} a \delta p \right) \right] \quad (7)$$

$$S_p = \frac{2}{N} \sum_{i=1}^N h_i \sin \left[ (i-1) \left( \frac{\pi}{180} a \delta p \right) \right] \quad (8)$$

From the Fourier coefficients in equations (7) and (8) desired harmonic constants are defined:

$$\zeta'(A) = \tan^{-1} \left( \frac{S_p}{C_p} \right) \quad (9)$$

$$R'(A) = (S_p^2 + C_p^2)^{1/2} \quad (10)$$

The quantity  $\zeta'(A)$  is the phase at  $t = 0$ , and  $R'(A)$  the amplitude for the constituent during the particular series of observations. Both symbols are primed, designating that the effects of other constituents have not been removed. For each constituent the quantity  $p$  in the coefficient equations equals the coefficient of the hour angle of the mean sun,  $T$ , in the equilibrium argument of that constituent.

Subroutine FORAN in the program does the entire Fourier summation for each desired constituent.  $R'$  and  $\zeta'$  are determined from the original series for five major constituents  $M_2$ ,  $S_2$ ,  $N_2$ ,  $O_1$ , and  $K_1$  and the harmonics  $M_4$ ,  $M_6$ ,  $M_8$ ,  $S_4$ , and  $S_6$ . In the case of a 15-day series of observations, the  $N_2$  constituent is approximated from the constants for  $M_2$ .

#### ASTRONOMICAL ADJUSTMENTS

Modifications of  $R'$  and  $\zeta'$  must be made to reduce these constants from the particular time of observation to mean values for an entire nodal period. The epochs of each constituent  $(V_0 + u)_n$  must be computed to adjust  $\zeta'_n$  to  $\kappa'_n$  and node factors  $f_n$  determined to resolve  $R'_n$  to  $H'_n$  for the entire nodal period.

#### Calculation of Orbital Functions

Prior to either adjustment, certain orbital elements and functions of these elements must be calculated. These are:

##### *Primary Orbital Elements*

- $s$ —mean longitude of the moon
- $p$ —mean longitude of lunar perigee
- $h$ —mean longitude of the sun
- $p_1$ —mean longitude of solar perigee
- $N$ —longitude of ascending lunar node
- $i$ —inclination of moon's orbit to plane of ecliptic
- $\omega$ —obliquity of the ecliptic

##### *Secondary Orbital Functions*

- $I$ —obliquity of the moon's orbit
- $\nu$ —longitude in the celestial equator (right ascension) of the moon's intersection with the equator
- $\xi$ —longitude in the moon's orbit of the moon's intersection with the celestial equator
- $\nu'$ —a function of the moon's orbit (this term appears in the argument of lunisolar constituent  $K_1$ )
- $2\nu''$ —another function of the moon's orbit (this term appears in the argument of lunisolar constituent  $K_2$ )
- $P$ —mean longitude of lunar perigee reckoned from lunar intersection in the celestial equator

Each of the orbital elements must be calculated for the beginning of the series before the epochs can be computed. The subroutines ASTRO and ORBIT compute these elements. Formulas for their determi-

nation used in the program and found in table 1 are compiled from Newcomb (1912) and Doodson (1924). Detailed discussion of these elements can be found in these references and in other works on celestial mechanics.

Computation of the secondary orbital functions are based on the assumption  $i$  and  $\omega$  are constant. This assumption may be reliable for as much as 4 centuries prior to or after the year 1900, as  $\omega$  is defined by the function

$$\omega = 23.45229444^\circ - 0.0130125^\circ T - 0.000001638^\circ T^2$$

and varies only 0.1 degree in 4 centuries. ( $T$  defined in table 1.) Formulas for the secondary orbital functions are given in table 2, based on Baird (1886) and Schureman (1924).

#### Computation of the Equilibrium Arguments

Equilibrium arguments  $(V + u)$  are combinations of the lunar and solar elements in the tidal equations derived from lunar and solar motion and are denoted by the symbol  $E(A)$ . They serve to identify the constituent and determine its speed and period, fixing times of extrema for the corresponding tidal force. When referring the argument  $E$  to the time at the beginning of a particular series, the argument becomes  $V_0 + u$ . The basic equations for computing the equilibrium arguments are taken from Schureman (1924). Equilibrium arguments for  $(MK)_3$ ,  $(2MK)_3$ ,  $(MN)_4$ ,  $(MS)_4$ ,  $(2SM)_2$ ,  $Mf$ ,  $MSf$ ,  $Mm$ ,  $Sa$ , and  $Ssa$  are omitted because they have negligible effect upon the maxima and minima for a short-period analysis.  $M_3$  and  $S_1$  are also omitted because their effects cannot be determined from a short period analysis.

#### Computation of Node Factors

The ratio of the true obliquity of the moon's orbit for any particular value of  $I$  to the mean value of the obliquity over an entire nodal period is called the *node factor*. This factor applied to the mean constituent amplitude for a nodal period yields the amplitude for the constituent at that particular value of  $I$ . Conversely, the reciprocal of the node factor applied to the tidal coefficients determined from a particular series reduces them to a mean value for the constituent for all positions of the lunar node. Equations used for computation of the node factors were extracted from Harris (1897) and Schureman (1941) and are shown in table 3.

TABLE 1.—*Formulas for computation of orbital elements*

Formulas for adjustment of orbital elements to beginning of century:

$$s' = 270.43742222^\circ + 307.892^\circ T + 0.002525^\circ T^2 + 0.00000189^\circ T^3 + s_o z$$

$$p' = 334.32801944^\circ + 109.0322055^\circ T - 0.01034444^\circ T^2 - 0.0000125^\circ T^3 + p_o z$$

$$h' = 279.69667778^\circ + 0.768925^\circ T + 0.0003025^\circ T^2 + h_o z$$

$$p_1' = 281.22083333^\circ + 1.719175^\circ T + 0.00045278^\circ T^2 + 0.00000333^\circ T^3 + p_{1o} z$$

$$N' = 259.18253333^\circ - 134.1423972^\circ T + 0.00210556^\circ T^2 + 0.00000222^\circ T^3 + N_o z$$

Formulas for adjustment of orbital elements to beginning of observations:

[For beginning of the series]

$$s = s' + 129.38482032 [Y-C] + 13.176396768 [D_s+X] + 0.549016532 \text{ [grbs]}$$

$$p = p' + 40.66246584 [Y-C] + 0.111404016 [D_s+X] + 0.004641834 \text{ [grbs]}$$

$$h = h' - 0.238724988 [Y-C] + 0.9856473288 [D_s+X] + 0.0410686387 \text{ [grbs]}$$

$$p_1 = p_1' + 0.1717836 [Y-C] + 0.000047064 [D_s+X] + 0.000001961 \text{ [grbs]}$$

[For middle of series]

$$p = p' + 40.66246584 [Y-C] + 0.111404016 [D_m+X] + 0.004641834 \text{ [grms]}$$

$$N = N' + 19.328185764 [Y-C] - 0.0529539336 [D_m+X] - 0.0022064139 \text{ [grms]}$$

$s_o, p_o, h_o, p_{1o}, N_o$ —Speeds of the elements (degrees/solar day)

$s', p', h', p_1', N'$ —Values of the elements at the beginning of any century

$s, p, h, p_1, N$ —Values of the elements at any given time

$T$ —Nearest whole number of Julian centuries (36525 days,) from Greenwich Mean Noon, December 31, 1899, on the Gregorian Calendar to the beginning of the century for observations

$Y$ —The exact year in which observations are recorded

$C$ —The century during which observations are recorded

$z$ —A factor representing the time difference (in solar days) formed between the Gregorian calendar date and the time  $T$  as calculated in Julian centuries

$D_s$ —The day of the year during which observations begin

$D_m$ —The day of the year upon which the midpoint of the series falls

$X$ —Correction for leap years

$$X = 0.25 [Y-(c+1)]$$

truncated to no decimals

grbs—Greenwich hour at the beginning of the series

grms—Greenwich hour at the middle of the series

TABLE 2.—*Formulas for secondary orbital functions*

$$\begin{aligned}
 I &= \cos^{-1} [0.9136949 - 0.0356926 \cos N]^* \\
 \nu &= \sin^{-1} [0.0897056 \sin N / \sin I]^* \\
 \xi &= \tan^{-1} \left[ \frac{(0.206727 \sin N)(1 - 0.0194926 \cos N)}{0.9979852 + 0.206727 \cos N - 0.0020148 \cos 2N} \right]** \\
 \nu' &= \tan^{-1} \left[ \sin \nu \div \left( \cos \nu + \frac{0.334766}{\sin 2I} \right) \right]** \\
 2\nu'' &= \tan^{-1} \left[ \sin 2\nu \div \left( \cos 2\nu + \frac{0.0726184}{\sin^2 I} \right) \right]** \\
 P &= [p \text{ (for middle of series)} - \xi]^* \\
 u \text{ of } L_2 &= 2(\xi - \nu) - R \pm 180^\circ* \\
 \text{where } R &= \tan^{-1} [\sin 2P / \{(\cos^2 0.5I / 6 \sin^2 0.5I) - \cos 2P\}] \\
 u \text{ of } M_1 &= (\xi - \nu) + Q + 90^\circ* \\
 \text{where } Q &= \tan^{-1} [\{5 \cos I - 1\} / (7 \cos I + 1)] \tan P]
 \end{aligned}$$

\*Schureman (1924)

\*\*Baird (1886)

TABLE 3.—*Formulas for calculation of node factor reciprocals*

$$\begin{aligned}
 F(A) \cdot f(A) &= 1.000 \\
 f(A) &= \text{node factor of constituent A.} \\
 F(M_2) &= (0.91544) \div (\cos^4 0.5 I) \\
 F(S_2) &= F(R_2) = F(T_2) = F(P_1) = F(S_4) = F(S_6) = 1.000 \\
 F(O_1) &= (0.37988) \div (\sin I \cos^2 0.5 I) \\
 F(K_1) &= (0.8965 \sin^2 2I + 0.6001 \sin 2I \cos \nu + 0.1006)^{-1/2} \\
 F(K_2) &= (19.0444 \sin^4 I + 2.7702 \sin^2 I \cos 2\nu + 0.0981)^{-1/2} \\
 F(L_2) &= F(M_2) \times [1 - (12 \sin^2 0.5 I \cos 2P) \div (\cos^2 0.5 I) + \\
 &\quad (36 \sin^4 0.5 I) \div (\cos^4 0.5 I)]^{-1/2} \\
 F(J_1) &= (0.72137) \div \sin 2I \\
 F(M_1) &= F(O_1) \times (2.310 + 1.435 \cos 2P)^{-1/2} \\
 F(OO) &= (0.016358) \div (\sin I \sin^2 0.5 I) \\
 F(N_2) &= F(2N) = F(\lambda_2) = F(\mu_2) = F(\nu_2) = F(M_2) \\
 F(Q_1) &= F(2Q) = F(P_1) = F(O_1) \\
 F(M_4) &= F^2(M_2) \\
 F(M_6) &= F^3(M_2) \\
 F(M_8) &= F^4(M_2)
 \end{aligned}$$

# INFERENCE OF $R'$ , $\kappa'$ , $\zeta'$ FOR SECONDARY CONSTITUENTS

Following the discussion of Schureman, the relations existing between observational constants of similar constituents are assumed the same as those existing between the corresponding theoretical values. Since values for only 10 constituents are sought ( $M_2$ ,  $S_2$ ,  $N_2$ ,  $O_1$ ,  $K_1$ ,  $M_4$ ,  $M_6$ ,  $M_8$ ,  $S_4$ ,  $S_6$ ), the other constituents, although minor in effect, must be approximate before the process of elimination can be applied to the major constituents. In the program this is done using the formulas given by Schureman (1941).

## ELIMINATION OF PERTURBATIONS FROM SECONDARY CONSTITUENTS

The disturbing effects upon  $S_2$  by  $K_2$  and  $T_2$  and on  $K_1$  by  $P_1$  may be considerable in a short series owing to the small differences in frequencies of the respective constituents. To correct for this, account is taken of the phase displacement and augmentation of amplitude in the major constituents  $S_2$  and

$K_1$  by the respective minor constituent disturbances. This process is described by Schureman (1941) and performed by the computer using the imbedded data from tables 21-26 from the *Manual of Harmonic Analysis and Prediction of Tides*.

The final process of elimination frees the constituents from the disturbing effects of the other constituents. The constituents sought are  $M_2$ ,  $N_2$ ,  $S_2$ ,  $O_1$ ,  $K_1$ . Only constituents with the same coefficient for the factor  $T$  in their equilibrium argument are considered interfering, that is, effects of diurnal upon semidiurnal and vice versa are negligible.

Complete discussion of constituent interference is found in Schureman (1941). The program completes the elimination process, using tables prepared from equations 389, 390 from Schureman (1941, table 29).

## HARMONIC CONSTANTS

Inference of secondary constituents from primary constituents utilizes the ratios derived by Schureman (1941) and shown in table 4.

TABLE 4.—*Formulas for inference of secondary constituents*

### Diurnal constituents

$$\begin{aligned} H(J_1) &= 0.079 H(O_1); \quad \kappa(J_1) = \kappa(K_1) + 0.496 [\kappa(K_1) - \kappa(O_1)] \\ H(M_1) &= 0.071 H(O_1); \quad \kappa(M_1) = \kappa(K_1) - 0.500 [\kappa(K_1) - \kappa(O_1)] \\ H(OO) &= 0.043 H(O_1); \quad \kappa(OO) = \kappa(K_1) + 1.000 [\kappa(K_1) - \kappa(O_1)] \\ H(P_1) &= 0.331 H(K_1); \quad \kappa(P_1) = \kappa(K_1) - 0.075 [\kappa(K_1) - \kappa(O_1)] \\ H(Q_1) &= 0.194 H(O_1); \quad \kappa(Q_1) = \kappa(K_1) - 1.496 [\kappa(K_1) - \kappa(O_1)] \\ H(2Q) &= 0.026 H(O_1); \quad \kappa(2Q) = \kappa(K_1) - 1.992 [\kappa(K_1) - \kappa(O_1)] \\ H(\rho_1) &= 0.038 H(O_1); \quad \kappa(\rho_1) = \kappa(K_1) - 1.429 [\kappa(K_1) - \kappa(O_1)] \end{aligned}$$

### Semidiurnal constituents

$$\begin{aligned} H(K_2) &= 0.272 H(S_2); \quad \kappa(K_2) = \kappa(S_2) + 0.081 [\kappa(S_2) - \kappa(M_2)] \\ H(L_2) &= 0.028 H(M_2); \quad \kappa(L_2) = \kappa(S_2) - 0.464 [\kappa(S_2) - \kappa(M_2)] \\ &= 0.143 H(N_2); \quad \kappa(L_2) = \kappa(M_2) + 1.000 [\kappa(M_2) - \kappa(N_2)] \\ H(N_2) &= 0.194 H(M_2); \quad \kappa(N_2) = \kappa(S_2) - 1.536 [\kappa(S_2) - \kappa(M_2)] \\ H(2N) &= 0.026 H(M_2); \quad \kappa(2N) = \kappa(S_2) - 2.072 [\kappa(S_2) - \kappa(M_2)] \\ &= 0.133 H(N_2); \quad \kappa(2N) = \kappa(M_2) - 2.000 [\kappa(M_2) - \kappa(N_2)] \\ H(R_2) &= 0.008 H(S_2); \quad \kappa(R_2) = \kappa(S_2) + 0.040 [\kappa(S_2) - \kappa(M_2)] \\ H(T_2) &= 0.059 H(S_2); \quad \kappa(T_2) = \kappa(S_2) - 0.040 [\kappa(S_2) - \kappa(M_2)] \\ H(\lambda_2) &= 0.007 H(M_2); \quad \kappa(\lambda_2) = \kappa(S_2) - 0.536 [\kappa(S_2) - \kappa(M_2)] \\ H(\mu_2) &= 0.024 H(M_2); \quad \kappa(\mu_2) = \kappa(S_2) - 2.000 [\kappa(S_2) - \kappa(M_2)] \\ H(\nu_2) &= 0.038 H(M_2); \quad \kappa(\nu_2) = \kappa(S_2) - 1.464 [\kappa(S_2) - \kappa(M_2)] \\ &= 0.194 H(N_2); \quad \kappa(\nu_2) = \kappa(M_2) - 0.866 [\kappa(M_2) - \kappa(N_2)] \end{aligned}$$

## USERS' GUIDE TO PROGRAM

The present program is written in FORTRAN-IV, executable with minor adjustments on any compatible machine having a 140K memory and access to arcsine and arccosine systems functions. Computing time is approximately 1.5 seconds on the CDC-6600.

Either a vector (polar form) or scalar variable may be analyzed. For vector series, the program allows either a major-minor axis analysis or a north-east component approach. No data series may exceed 7,000 terms without redimensioning in the program, and no series of other than 15 or 29 days of uniformly spaced data can be analyzed.

The program accepts input via magnetic tape or punched cards in any format with the restriction that, for vectors with magnitude and direction in the same record, the angles must precede the amplitudes in the record. For vectors specified by one

file of amplitudes and one file of directions, the amplitude file must be read first.

Output comprises the mean amplitudes and phases of 26 tidal constituents.

### EXPLANATION OF CONTROL CARDS

The order of the control cards (fig. 1) input to the machine is of utmost importance. The discussion of each card or set of cards is in the order in which they are read. The master job control card appears only once, whereas all other cards appear for each new data series.

#### Master Job Control Card

Immediately following the program deck must be a card containing the quantity NJ. This specifies the number of different jobs to be done.

READ 221, NJ  
221 FORMAT (I5)

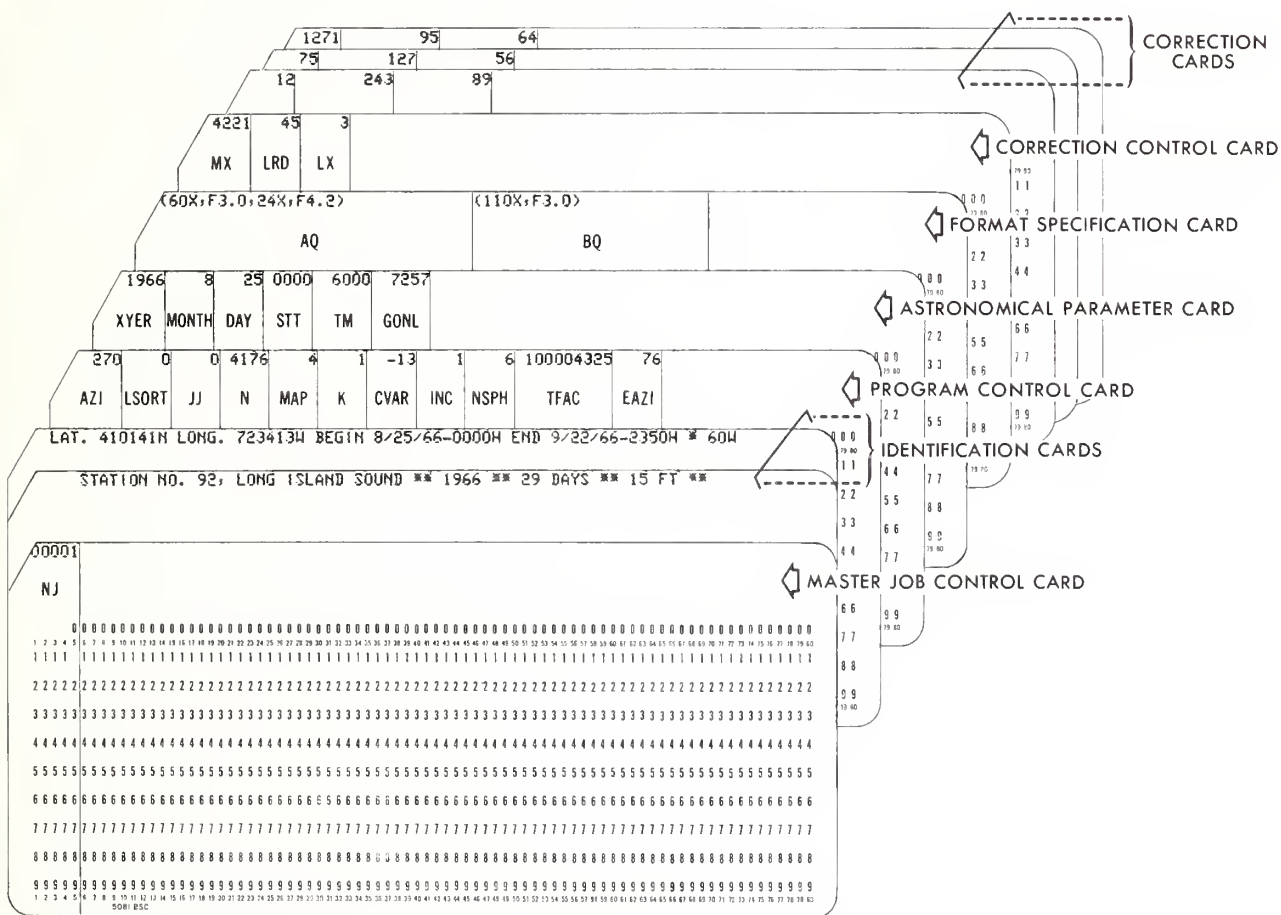


FIGURE 1.—Order of control cards. If data are on cards, data deck(s) follow the format specification card and the correction cards are not applicable.

### Identification Cards

These two cards follow the master job control card and are read by the statement.

READ 808, IDENS  
808 FORMAT (9A8/9A8)

The purpose of these cards is to introduce any desired alphanumeric information to be used as identifications. Contents of these two cards will be printed *verbatim* immediately preceding final results. Only columns 1-72 of each card will be printed.

### Program Control Card

The program card specifies the operations to be performed on the data series, the mode of input for data series, and any adjustments which are to be made to the data. The variables are read by the statement

READ 76, AZI, LSORT, JJ, N, MAP, K,  
CVAR, INC, NSPH, TFAC, EAZI  
76 FORMAT (F5.0, 5I5, F5.0, 2I5, F10.8, F5.0)

The variables listed have the following significance:

AZI—Approximate mean flood direction (F5.0)

LSORT—Specifies when a sort of the input data is required (I5)

LSORT = 0. No sort

LSORT = 1. Sort to be performed

JJ—Indicates the type of sort desired (I5) (See subroutine SORT)

N—The number of data points in the series (I5)

MAP—Controls input mechanism and format. MAP is determined partially by whether the data are vector or scalar. (I5)

MAP = 1. Scalar quantity, card input with format AQ. (See format specification card)

MAP = 2. Magnetic tape input for vector quantity with format AQ. Angles must precede magnitudes in the record

MAP = 3. Card input of vector data with magnitudes of format AQ and directions of format BQ.

MAP = 4. Tape input of vector data according to format AQ and tilt corrections from tape (if available) according to format BQ. Use MAP = 4 only for making corrections to data series. (See subroutine EDAT)

K—Indicates whether analysis by components is desired (I5)

K = 1. Major axis analysis only (use K = 1 for scalar)

K = 2. Minor axis analysis only

K = 3. Major and minor axis analysis

K = 4. North and east component analysis. In this case AZI = 0.00

CVAR—Compass variation of the vicinity. CVAR is negative when West and positive when EAST. (F5.0)

INC—Indicate if tilt corrections are to be applied. (See subroutine TILT) (I5)

INC = 0. No tilt corrections

INC = 1. Tilt corrections to be applied

NSPH—Number of samples of data per mean solar hour (I5)

TFAC—Time correction factor for a slow or fast chronometer in meters. (F10.8) For no time correction TFAC = 1.000000. To determine TFAC use the expression

$$\text{TFAC} = \frac{\text{True time covered by observations}}{\text{Time reckoned by the meter clock}}$$

CAUTION: If NSPH or TFAC is zero, the program will terminate immediately.

EAZI—approximate ebb azimuth (F5.0)

### Astronomical Parameter Card

The card specified in the statement

READ 2038, XYER, MONTH, DAY, STT,  
TM, GONL  
2038 FORMAT (F5.0, I5, F5.0, F5.2, 2F6.2)

inputs information which is pertinent to the particular times of the series of observations.

XYER—Year in which the series is observed (F5.0)

MONTH—Month during which series starts (I5)

DAY—Day on which series starts (F5.0)

STT—Time in decimal hours at which series starts (F5.2)

TM—Time meridian to which station is referred (F6.2)

GONL—Longitude of the station (F6.2)

**CAUTION:** The convention of west longitude being positive and east longitude being negative is followed in entering the parameters TM and GONL-

### Format Specification Card

This card allows variability in the format of data on magnetic tape or cards. This card is read by the statement

READ 2039, AQ, BQ  
2039 FORMAT (4A8, 3A8)

The maximum field length of AQ is 32 characters and of BQ is 24 characters. The format specification BQ must always begin in column 33 of this card. Parenthesis must be punched and counted as part of the field length.

Limitations are according to the variable MAP:

MAP = 1. Assign AQ a card format; do not assign BQ.

MAP = 2. Assign AQ a tape format; do not assign BQ. Angle of vector must precede the magnitude in the record.

MAP = 3. Assign AQ and BQ formats for card reading. AQ must be magnitudes of the vectors and BQ must be directions.

MAP = 4. AQ and BQ must be as follows:  
AQ = (60X, F3.0, 24X, F4.2)  
BQ = (110X, F3.0)

This is necessary for tilt corrections.

### Correction Control Card

If data are on cards, data decks immediately follow the format specification card. For data read from magnetic tape, corrections can be made using the correction control card.

READ 222, MX, LRD, LX  
222 FORMAT (3I5)

MX—Total number of records which will be read to attain desired series  
MX = N + LRD

LRD—Number of records at beginning of tape to be skipped

LX—Number of corrections to be read from cards and substituted in the series for those values found on the magnetic tape

Correction cards follow the correction control card and contain the interval number of the point to be changed and the desired angle and magnitude of the vector at that point. The statement

READ 555, (ICOR (LY), CD (LY),  
CV (LY), LY = 1, LX)  
555 FORMAT (I5, F10.0, F10.2)  
reads these parameters.

### EXPLANATION OF SUBROUTINES

The subroutines called in program CURAN can be grouped into three categories. The mathematical analysis and astronomical adjustments are performed in four basic subroutines—FORAN, ORBIT, ASTRO, SASTR. The subroutine DAYXX is a utility routine used for adjusting the time of beginning of series to astronomical reference frame (Greenwich Time Meridian). Operations peculiar to tidal currents are performed by subroutines AZIM, DETAZ, and TILT.

Utility routines which are called or in some cases are optional include SORT, EDAT, MEAN, TERPO, TEMP, FITAN, ONEPI, and TWOPI.

#### Subroutine FORAN (SER, SP, RES, ZEP, N, M)

This subroutine is designed to determine the Fourier coefficients of the data (SER) for the first approximations of phases (ZEP) and amplitudes (RES) of the various constituents. The angular displacement per sampling period (SP) of the required constituent is computed in the subroutine according to the expression:

$$SP = \frac{(\text{Speed of the constituent in degrees per mean solar hour})}{(\text{Number of samples per hour} \times 180)}$$

The numbers N and M represent the number of data points and the number of harmonics sought, respectively. The subroutine uses equations (289) and (292) from Schureman to obtain the Fourier coefficients.

#### Subroutine SASTR

This subroutine calls as input the reciprocals (CF) of the node factors of the various constituents computed in the main program according to equations (73)-(80), (141)-(150), (207), (215), and (235). The input also comprises the node factor for  $K_2$  (CKKF), the mean longitude of the sun (SL), the arguments

for  $\nu'$ ,  $\nu''$  (VP, VPP), and the mean longitude of solar perigee (PS). Tables 21-26 from Schureman are embedded in the program. The following effects of secondary constituents are computed:

ACS—Acceleration in  $S_2$  from  $K_2$  and  $T_2$

APS—Augmentation of amplitude of  $S_2$  from  $K_2$  and  $T_2$

ACK—Acceleration in  $K_1$  from  $P_1$

APK—Augmentation of amplitude of  $K_1$  from  $P_1$

This subroutine calls subroutine TERPO to interpolate the appropriate tables.

Subroutine ASTRO (XYER, DAYB, DAYM,  
GRBS, GRMS, JOBX)  
COMMON/COSTX/CXX(30), OEX(5)

This subroutine uses input from subroutine DAYXX (DAYB, DAYM, GRBS, GRMS) with the input value XYER, the year in which observations begin, to compute the orbital elements  $s$ ,  $p$ ,  $h$ ,  $p_1$ ,  $N$ ,  $I$ ,  $\nu$ ,  $E$ ,  $\nu'$ , and  $2\nu''$  (table 1) relative to the period of observation. The subprogram calls subroutine ORBIT to compute all values for the beginning of the century, then adjusts each to the time of the observed series. The array CXX are the appropriate values of the orbital elements. JOBX is the number of days in the data series.

Subroutine ORBIT (XCEN, XSX, SPX, SHX,  
XPIX, XNX, OEX, T, XYER, NNN)

This subroutine uses the value XYER to compute orbital elements (table 1) for the beginning of the century during which observations were taken. The elements are computed according to the expressions given by Newcomb and Schureman displayed in table 1. Values are computed in array OEX and transferred to the variables XSX, XPX, XHX, XPIX, XNX for convenience. XCEN, T, NNN are all internal variables.

Subroutine TERPO

This subprogram is a utility program designed to interpolate a table of figures in two directions.

Subroutine SORT (SORX, VK, KK, JJ)

This is designed to sort values from an array (SORX) forming a new array (VX) such that the

new array consists of the first value and every JJth value thereafter of the original series. KK is internal and dimensions the new array VX.

Subroutine EDAT (MX, VIN, DIN, MA, LX,  
ICOR, CD, CV, LRD, XTEMP, INC)

This routine is available only to MAP = 4. It is designed for cases where polar vectors are input as data from magnetic tape, but either simple substitutions or tilt corrections need to be applied to the data series.

MX—MA + LRD

VIN—Magnitudes (corrected)

DIN—Directions (corrected)

MA—Total number of values desired in final data series

LX—Number of substitutions and inferences to be made within the series or at end of series

ICOR—Interval number in the list MX which is to be corrected

CD—Angle to be substituted for the value actually on tape

CV—Magnitude to be substituted for the value actually on tape

LRD—Number of records on tape to be skipped

XTEMP—Temporary storage for TILT values

INC—Integer indicating when tilt corrections are to be applied

CAUTION: If a magnitude or direction for a given interval need correcting, both magnitude and direction and interval number must be punched on a card. The program substitutes the entire record. Format for correction cards bearing ICOR, CD, CV is (I5, F10.0, F10.2). The number of substitutions used may not exceed 300.

If an inference of data is required to extend the series to the required length of 15 or 29 days, the magnitudes and directions must be punched on cards with the formats (24F3.2) and (24F3.0), respectively. These cards then follow any substitution cards in the data deck.

Subroutine XMEAN

This is a utility routine to compute the arithmetic mean of an array.

#### Subroutine DAYXX

Computes the day of the year and the Greenwich hour for the beginning and middle of the data series.

#### Subroutine TEMP

Provides temporary storage for any array so that operations can be performed on the array without loss of the original series.

#### Subroutine FITAN

This subprogram finds the angle for a given value of the arctangent function.

#### Subroutine ONEPI

This subroutine is designed to prevent the difference between two angles from exceeding 180 degrees or becoming negative.

#### Subroutine TWOPI

This subroutine places a given angle in the proper quadrant.

#### Subroutine AZIM (DX, VR, A, VN, K, J, COMPV)

This subprogram is designed to compute the vector components along major and minor axes or to determine north and east components.

DX, VR—Angles, magnitudes of popular vector

A—Azimuth ( $A = 0$ . North and east components)

VN—New component series which is formed

K—Indicates type of component formed

K = 1. Major axis; north component

K = 2. Minor axis; east component

J—Number of data values in series

COMPV—Magnetic variation in directions if the directions are not true readings

#### Subroutine DETAZ

This routine is designed to compute a mean major axis azimuth for a given approximate azimuth which is input on the master job control card.

#### Subroutine TILT

This subroutine is designed for correcting erroneous tidal current velocities for instrumental tilt. It should be applied only to instruments having Savonius rotor current sensors with tilt meters. If the tilt reading exceeds 35 degrees, a manual inference will be required.

#### REFERENCES

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Harris, R. A., "Manual of Tides," Appendix No. 8 to 1897 Annual Report of U.S. Coast and Geodetic Survey, U.S. Department of Commerce, Washington, D.C., 1898.

Newcomb, Simon, *Astronomical Papers for the American Ephemeris*, Vol. IX, Part I, 1912.

Schureman, P. W., *Manual of Harmonic Analysis and Prediction of Tides*, C&GS Special Publication No. 98, Revised (1940) Edition, U.S. Department of Commerce, Washington, D.C., 1941.

Schureman, P. W., *Manual of Harmonic Analysis and Prediction of Tides*, C&GS Special Publication No. 98, Serial No. 244, U.S. Department of Commerce, Washington, D.C., 1924.



# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES

```

ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION - C.+ G.S.
FOURIER - HARMONIC ANALYSIS PROJECT 131403 29 DAYS
PROGRAM CURAN (INPUT OUTPUT TAPF9)
DIMENSION VIN(9000)'DIN(9000)'CHSIP(10)'CRP(10)'CONU(25)'CF(25)'
1TXXIX1( 5'20)'TXXIX2(5'20)'CKAPAP(20)'CKAP(20)'CHSI(20)'CR(20)'
2RELL(20)'BINGO(20)'G(5)'PAK(5)'D(24)'W(24)'ZETA(5)'CRC(5)
DIMENSION RES(4)'ZEP(4)'XTEMP(9000)'VN(9000)'ITEMP(9000)
DIMENSION CV(300)'CD(300)'ICOP(300)'IDENS(18)
DIMENSION CXX(30)'DEG(40)'TAB1(40)'TAB2(40)'TAB3(40)'TAB4(40)
DIMENSION TAB5(40)'TAB6(40)'AQ(4)'BQ(3)'OEX(5)
DIMENSION TXXIXA(20)'TXXIXB(20)'TXXIXC(20)'TXXIXD(20)'TXXIXE(20)
DIMENSION TXXIXF(20)'TXXIXG(20)'TXXIXH(20)'TXXIXI(20)'TXXIXJ(20)
COMMON/FORT/AQ/BQ/COSTX/CXX/OEX/CONTT/NN
COMMON / LEAPYR / DAY/MONTH

```

SPEEDS OF CONSTITUENTS M(2)'N(2)'S(2)'O(1)'K(1) FOR 1 SAMPLE/HP.

```

DATA SXM2'SXS2'SXN2'SXN1'SXK1/0.1610228'0.1666667'0.1579985'0.0774 15
1613'0.0835615/ 16

```

TABLE XXIX FROM SCHUREMAN' S.P. 98 (1941)

ACCELERATION IN EPOCH OF K(1) DUE TO P(1)' 29 DAYS

```

DATA(TAB1(JZ)'JZs1'18)/11.4'16.4'18.3'17.6'15.2'11.7'7.4'2.7'-2.2' 1
1-6.9' 11.3'-14.9'-17.5'-18.3'-16.7'-12.1'-4.7'3.9/ 2

```

RATIO OF INCREASE IN AMPLITUDE OF K(1) DUE TO P(1)'29DAYS

```

DATA(TAB2(JZ)'JZs1'18)/-0.26'-0.17'-0.06'0.04'0.14'0.23'0.28'0.31' 3
10.32' .29'0.23'0.15'0.05'-0.06'-0.16'-0.25'-0.30'-0.31/ 4

```

ACCELERATION IN EPOCH OF S(2) DUE TO K(2)' 29DAYS

```

DATA(TAB3(JZ)'JZs1'18)/5.9'9.6'12.6'14.6'15.0'13.5'9.6'3.7'-3.0'-9 5
1.1'-13.2'-15.0'-14.7'-12.9'-10.0'-6.4'-2.3'1.9/ 6

```

RATIO OF INCREASE IN AMPLITUDE OF S(2) DUE TO K(2)'29DAYS

```

DATA(TAB4(JZ)'JZs1'18)/0.24'0.19'0.12'0.04'-0.05'-0.14'-0.21'2*-0. 7
125'-0.21'-0.15'-0.06'0.03'0.11'0.18'0.23'2*0.26/ 8

```

ACCELERATION IN EPOCH OF S(2) DUE TO T(2)' 29 DAYS

```

DATA(TAB5(JZ)'JZs1'37)/-0.8'-1.3'-1.8'-2.2'-2.6'-2.9'-3.2'3*-3.3'- 9
13.1'-2.8'-2.5'-2.0'-1.5'-0.9'-0.3'0.3'0.9'1.5'2.0'2.4'2.8'3.1'3*3. 10
23'3.2'3.0'2.7'2.3'1.9'1.4'0.8'0.3'-0.2'-0.8/ 11

```

RESULTANT AMPLITUDE IN S(2) DUE TO T(2)' 29 DAYS

```

DATA(TAB6(JZ)'JZs1'37)/1.06'2*1.05'1.04'2*1.03'1.02'1.01'1.00'0.99 12
1'0.98'0.97'0.96'2*0.95'4*0.94'2*0.95'0.96'0.97'0.98'0.99'1.00'1.01 13
2'1.02'2*1.03'1.04'2*1.05'4*1.06/ 14

```

AMPLITUDE EFFECT OF CONSTITUENTS ON M(2)' 29 DAYS

```

DATA(TXXIXA( J )'JJs1'20)/0.0'0.050'0.018'2*0.0'0.056'0.050'0.049'0 17
1.021' .060'0.096'0.018'0.096'7*0.0/ 18

```

AMPLITUDE EFFECT OF CONSTITUENTS ON N(2)' 29 DAYS

```

DATA(TXXIXB( J )'JJs1'20)/0.050'0.00'0.005'2*0.0'0.052'0.049'0.050' 19
10.031'0.021'0.018'0.096'0.968'7*0.0/ 20

```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

## AMPLITUDE EFFECT OF CONSTITUENTS ON S(2)' 29 DAYS

DATA(TXXIXC( J )'Js1'20)/0.018'0.005'3\*0.0'0.959'0.096'0.017'2\*0.9 21  
190'0. 50'0.018'0.042'7\*0.0/ 22

## AMPLITUDE EFFECT OF CONSTITUENTS ON O(1)' 29 DAYS

DATA(TXXIXD( J )'Js1'20)/4\*0.0'0.056'8\*0.0'0.052'0.065'0.052'0.018 23  
1'0.05 '0.049'0.096/ 24

## AMPLITUDE EFFECT OF CONSTITUENTS ON K(1)' 29 DAYS

DATA(TXXIXE( J )'Js1'20)/3\*0.0'0.056'9\*0.0'2\*0.050'0.056'0.959'0.0 25  
152'0. 49'0.011/ 26

## PHASE EFFECT OF CONSTITUENTS ON M(2)' 29 DAYS

DATA(TXXIXF( J )'Js1'20)/0.0'351.'174.'2\*0.0'22.'9.'341.'8.'159.'1 27  
164.'186.'196.'7\*0.0/ 28

## PHASE EFFECT OF CONSTITUENTS ON N(2)' 29 DAYS

DATA(TXXIXG( J )'Js1'20)/9.'0.0'3.'2\*0.0'32.'19.'351.'17.'169.'174 29  
1.'196.'25.'7\*0.0/ 30

## PHASE EFFECT OF CONSTITUENTS ON S(2)' 29 DAYS

DATA(TXXIXH( J )'Js1'20)/186.'357.'3\*0.0'29.'196.'348.'14.'346.'35 31  
11.'193.'202.'7\*0.0/ 32

## PHASE EFFECT OF CONSTITUENTS ON O(1)' 29 DAYS

DATA(TXXIXI( J )'Js1'20)/4\*0.0'22.'8\*0.0'32.'13.'44.'174.'351.'341 33  
1.'196./ 34

## PHASE EFFECT OF CONSTITUENTS ON K(1)' 29 DAYS

DATA(TXXIXJ( J )'Js1'20)/3\*0.0'338.'9\*0.0'9.'351.'22.'331.'328.'31 35  
19.'354./ 36

## LOADING OF TABLES INTO PROPER ARRAYS

```
DO 80 8 MAXJ s 1'20
TXXIXJ(1'MAXJ) s TXXIXA(MAXJ)
TXXIX1(2'MAXJ) s TXXIXR(MAXJ)
TXXIX1(3'MAXJ) s TXXIXC(MAXJ)
TXXIX1(4'MAXJ) s TXXIXD(MAXJ)
TXXIX1(5'MAXJ) s TXXIXF(MAXJ)
TXXIX2(1'MAXJ) s TXXIXF(MAXJ)
TXXIX2(2'MAXJ) s TXXIXG(MAXJ)
TXXIX2(3'MAXJ) s TXXIXH(MAXJ)
TXXIX2(4'MAXJ) s TXXIXI(MAXJ)
R008 TXXIX2(5'MAXJ) s TXXIXJ(MAXJ)
```

## CONTROL CARDS ENTERED

```
READ 221'NJ
DO 1111 JN s 1'NJ
READ 808'(IDENS(JK)'JK s 1'18)
READ 76' AZI'LSORT'JJ'N'MAP'K'CVAR'INC'NSPH'TFAC'EAZI
READ 2038'XYER'MONTH'DAY'STT'TM'GONL
READ 2039' AQ' R0
IF(NSPH.EQ.0.0.OR.TFAC.EQ.0.0) GO TO 8356
```

## DATA INPUT LOOP BEGINS

```
GO TO (101'102'103'660'661)'MAP
661 READ AQ'(DIN(KX)'VIN(KX)'KX s 1'N)
GO TO 104
101 READ AQ'(VIN(I)'I s 1'N)
GO TO 123
103 READ AQ'(VIN(I)' I s 1'N)
IF(AZI.EQ.0.0.AND.K.EQ.0) GO TO 123
READ BQ'(DIN(I)' I s 1'N)
GO TO 104
123 IF(LSORT - 1) 120'121'121
120 CALL TEMP(VIN'XTFMP'N)
GO TO 108
```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

```

121 CALL SORT(VIN'XTFMP'N'JJ)
   N s NN
   GO TO 108
102 READ(9'AQ)(DIN(I)' VIN(I))I s 1'N)
   IF(K.EQ.5) GO TO 120
   GO TO 104
660 READ 222'MX'LRD' LX
   IF(LX.EQ.0) GO TO 666
   READ 555'(ICOR(LY))'CD(LY)'CV(LY)'LY s 1' LX)
666 CALL EDAT(MX'VIN'DIN'N' LX'ICOR'CD'CV'LRD'XTFMP'INC)
104 NECOM s 1
   IF(K.EQ.3) NECOM s 3
   IF(K.EQ.4) NECOM s 4
   IF(NECOM.EQ.3.OR.NECOM.EQ.4) K s 1
   IF(NECOM.EQ.4) GO TO 8355
   CALL DETAZ(DIN'AZI'N'CVAR'VIN'XTFMP'INC)
   FLX s AZI
   IF(EAZI.EQ.0.0) GO TO 8355
   CALL DETAZ(DIN'EAZI'N'CVAR'VIN'XTFMP'0)
   EBX s FAZI
   DIRE s FLX - FBX
   ATZ s .0
   PIPE s ABS(DIRE)
   IF(PIPE.GT.180.0) ATZ s PIPE - 180.0
   IF(PIPE.LT.180.0) ATZ s 180.0 - PIPE
   ARZ s ATZ/2.0
   ZAR s AINT(ARZ)
   IF(DIRE.LT.0.0) AZI s FLX + ZAR
   IF(DIRE.GT.0.0) AZI s FLX - ZAR
   PRINT 7359' AZI'DIRE'ARZ'ZAR
8355 CALL AZIM(DIN'VIN'AZI'VN'K'N'CVAR'NECOM)
   IF(LSORT - 1)107'106'106
106 CALL SORT(VN'XTFMP'N'JJ)
   N s NN
   GO TO 108
107 CALL TEMP(VN'XTFMP' N)

```

FOURIER ANALYSIS PERFORMED FOR FIVE MAJOR TIDAL FREQUENCIES

```

108 XM2 s TFAC*SXM2/FLOAT(NSPH)
   XS2 s TFAC*SXS2/FLOAT(NSPH)
   XN2 s TFAC*SXN2/FLOAT(NSPH)
   XO s TFAC*SXO1/FLOAT(NSPH)
   XK s TFAC*SXK1/FLOAT(NSPH)
   GO TO 8357
8356 PRINT 7358
   CALL EXIT
8357 CALL FORAN(XTEMP'XM2'RES'ZEP'N'4)
   CHSIP(1) s ZEP(1)
   CHSIP(6) s ZEP(2)
   CHSIP(7) s ZEP(3)
   CHSIP(8) s ZEP(4)
   CRP(1) s RES(1)
   CRP(6) s RES(2)
   CRP(7) s RES(3)
   CRP(8) s RES(4)
110 CALL FORAN(XTEMP'XN2' RES'ZEP' N' 1)
   CHSIP(2) s ZEP(1)
   CRP(2) s RES(1)
111 CALL FORAN(XTEMP'XS2' RES'ZEP' N' 3)
   CHSIP(3) s ZEP(1)
   CHSIP(9) s ZEP(2)
   CHSIP(10) s ZEP(3)
   CRP(3) s RES(1)
   CRP(9) s RES(2)
   CRP(10) s RES(3)
   CALL FORAN(XTEMP'XO' RES' ZEP' N' 1)
   CHSIP(4) s ZEP(1)
   CRP(4) s RES(1)
   CALL FORAN(XTEMP'XK' RES' ZEP' N' 1)
   CHSIP(5) s ZEP(1)

```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

```

CRP(5) s RES(1)
CALL TWOPI(CHSIP'10)
IF(NECOM.EQ.3.OR.NECOM.EQ.4) GO TO 8058
GO TO 8057
8058 IF(K.EQ.2) GO TO 8059

```

DETERMINATION OF VO+ U FOLLOWS WITH LOGF AND ARGUMENTS

```

8057 CALL DAYXX(MONTH'DAY'STT'TM'DAYB'DAYM'GRES'GRMS'CP)
DO 7135 JAN s 1'19
LXN s JAN + 18
TAB1(LXN) s TAB1(JAN)
TAB2(LXN) s TAB2(JAN)
TAB3(LXN) s TAB3(JAN)
7135 TAB4(LXN) s TAB4(JAN)
CALL ASTRO(XYER'DAYB'DAYM'GRBS'GRMS'29)
PM s CXX(1)
PL s CXX(2)
SL s CXX(3)
PS s CXX(4)
PLM s CXX(5)
SKYN s CXX(6)
VI s CXX(9)
V s CXX(10)
XI s CXX(11)
VP s CXX(12)
VPP s CXX(13)
P s CXX(14)
AUL s CXX(15)
AUM s CXX(16)
PAPA s 0.0
DO 3073 NAP s 1'37
DFG(NAP) s PAPA
3073 PAPA s PAPA + 10.0

```

DETERMINATION OF EQUILIBRIUM ARGUMENTS (VO + U)

```

7777 TML s CP - GONL
CON s SL + TML
COVU(1) s 2.0*(CON - PM + XI - V)
COVU(2) s COVU(1) - (PM - PL)
COVU(3) s 2.0*(TML)
COVU(4) s CON - V - 2.0*(PM - XI) - 90.0
COVU(5) s CON - VP + 90.0
COVU(6) s 2.0*CON - VPP
COVU(7) s 2.0*CON - PM - PL + AUL
COVU(8) s COVU(2) - (PM - PL)
COVU(9) s SL - PS + 180.0 + 2.0*(TML)
COVU(10) s COVU(2) - (SL - PS)
COVU(11) s COVU(1) - (2.0*(SL - PM)) - (PM - PL) + 180.0
COVU(12) s COVU(1) + 2.0*(SL - PM)
COVU(13) s COVU(12) + (PM - PL)
COVU(14) s CON + PM - PL - V + 90.0
COVU(15) s CON - PM + AUM
COVU(16) s CON - V + 2.0*(PM - XI) + 90.0
COVU(17) s TML + 270.0 - SL
COVU(18) s COVU(4) - (PM - PL)
COVU(19) s COVU(18) - (PM - PL)
COVU(20) s COVU(18) + 2.0*(SL - PL)
COVU(21) s 2.0*(COVU(1))
COVU(22) s 3.0*(COVU(1))
COVU(23) s 4.0*(COVU(1))
COVU(24) s 2.0*(COVU(2))
COVU(25) s 3.0*(COVU(2))
CALL TWOPI(COVU'25)

```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

```

DETERMINATION OF NODE FACTOR RECIPROALS (F)
V s V*.0174533
P s P*.0174533
VI s VI*.0174533
CPA s 1.0/SQRT(1.0 - 12.0*(SIN(.5*VI)**2/COS(.5*VI)**2)*COS(2.0*P)
1+ 26. *(SIN(.5*VI)**4/COS(.5*VI)**4))
CQA s 1.0/SQRT(2.310 + 1.425*COS(2.0*P))
CF(1) s 1.0/(COS(.5*VI)**4/.91544)
CF(2) s CF(1)
CF(3) s 1.0
CF(4) s 1.0/(SIN(VI)*COS(.5*VI)**2/.37988)
CF(5) s 1.0/SQRT(0.8965*SIN(2.0*VI)**2 + 0.6001*SIN(2.0*VI)*COS(V)
1+ 0.1 6)
CF(6) s 1.0/SQRT(19.0444*SIN(VI)**4 + 2.7702*SIN(VI)**2*COS(2.0*V)
1+ 0.0981) - 0.000999
CF(7) s CF(1)*CRA
CF(8) s CF(1)
CF(9) s 1.0
CF(10) s 1.0
CF(11) s CF(1)
CF(12) s CF(1)
CF(13) s CF(1)
CF(14) s 1.0/(SIN(2.0*VI)/0.72137)
CF(15) s CF(4)*CQA
CF(16) s 1.0/(SIN(VI)*SIN(.5*VI)**2/0.016358)
CF(17) s 1.0
CF(18) s CF(4)
CF(19) s CF(18)
CF(20) s CF(19)
CF(21) s CF(1)**2
CF(22) s CF(1)**3
CF(23) s CF(1)**4
CF(24) s 1.0
CF(25) s 1.0
CKKF s 1.0/CF(6)
AHNAT s CF(4)*CRP(4)
C5F s CF(5)

```

ENTER SECONDARY EFFECTS AND DETERMINE KAPPA

```

CALL SASTR(DEG'C5F'CKKF'SMAC'PROD'ACCP'RESAM'37'TAR1'TAB2'TAB3'TAB
14'TAB5'TAB6'SL'VPP'PS'VP'CF'25)
8059 DO 21 I s 1'5
21 CKAPAP(I) s CHSIP(I) + COVU(I)
CALL TWOPI(CKAPAP' 5)
CKAP(1) s CKAPAP(1)
CKAP(2) s CKAPAP(2)
CKAP(3) s CKAPAP(3) + SMAC
CKAP(4) s CKAPAP(4)
CKAP(5) s CKAPAP(5) + ACCP
CKAP(6) s CKAP(3)
DMN s CKAP(1) - CKAP(2)
CALL ONEPI(DMN)
CKAP(7) s CKAP(1) + DMN
CKAP(8) s CKAP(2) - DMN
CKAP(9) s CKAP(3)
CKAP(10) s CKAP(3)
SMD s CKAP(3) - CKAP(1)
CALL ONEPI(SMD)
CKAP(11) s CKAP(1) + 0.464*SMD
CKAP(12) s CKAP(1) - SMD
CKAP(13) s CKAP(1) - 0.866*DMN
OKD s CKAP(5) - CKAP(4)
CALL ONEPI(OKD)
CKAP(14) s CKAP(5) + 0.5*OKD
CKAP(15) s CKAP(5) - 0.5*OKD
CKAP(16) s CKAP(5) + OKD
CKAP(17) s CKAP(5)
CKAP(18) s CKAP(5) - 1.5*OKD
CKAP(19) s CKAP(5) - 2.0*OKD
CKAP(20) s CKAP(5) - 1.43*OKD
CALL TWOPI(CKAP'20)

```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

DETERMINATION OF ZETA(A) AND R(A) FOLLOWS

```

DO 22 I s 1'20
22 CHSI(I) s CKAP(I) - COVU(I)
CALL TWOPI(CHSI' 20)
CR(1) s CRP(1)
CR(2) s CRP(2)
CR(3) s CRP(3)/PPOD
CR(4) s CRP(4)
CR(5) s CRP(5)/RESAM
CR(6) s 0.272*CR(3)/CF(6)
CR(7) s 0.145*CR(2)/CRA
CR(8) s 0.133*CR(2)
CR(9) s 0.008*CR(3)
CR(10) s 0.059*CR(3)
CR(11) s 0.007*CR(1)
CR(12) s 0.024*CR(1)
CR(13) s 0.194*CR(2)
CR(14) s 0.079*AHNAT/CF(14)
CR(15) s 0.071*CR(4)/CQA
CR(16) s 0.043*AHNAT/CF(16)
CR(17) s 0.331*CR(5)*CF(5)
CR(18) s 0.194*CR(4)
CR(19) s 0.026*CR(4)
CR(20) s 0.038*CR(4)

```

ELIMINATION OF COMPONENT EFFECTS AND DETERMINE KAPPA AND H(A)

```

DO 35 I s 1'5
SUM s .0
SOQ s .0
DO 20 J s 1'20
331 BELL(J) s CR(J)*TXXIX1(I'J)
IF(BELL(J)-.0005)23'24'24
23 BELL(J) s 0.0
24 BINGO(J) s TXXIX2(I'J) - CHSI(J) + CHSIP(I)
IF(BINGO(J))25'28'26
25 BINGO(J) s ( BINGO(J) + 360.)*0.0174533
GO TO 29
26 IF(BINGO(J) - 360.0) 28'28'27
27 BINGO(J) s (BINGO(J) + 360.0)*0.0174533
GO TO 29
28 BINGO(J) s BINGO(J)*0.0174533
29 SUM s SUM + BELL(J)*SIN(BINGO(J))
20 SOQ s SOQ + BELL(J)*COS(BINGO(J))
QOS s CRP(1) - SOQ
CALL FITAN(SUM'QOS'DCCH'2)
DCCH s DCCH*0.0174533
CRC(I) s 0.0
IF(DCCH.EQ.90.0.OR.DCCH.EQ.270.0) GO TO 34
CRC(I) s (CRP(1) - SOQ)/COS(DCCH)
34 G(I) s CRC(I)*CF(I)
ZETA(I) s CHSIP(I) + DCCH*57.29578
35 PAK(I) s CHSIP(I) + DCCH*57.29578 + COVU(I)
CALL TWOPI(PAK' 5)

```

INFERENCE OF H(A) FROM MAJOR CONSTITUENTS

```

D(1) s 0.079*G(4)
D(2) s G(5)
D(3) s 0.272*G(3)
D(4) s 0.028*G(1)
D(5) s 0.071*G(4)
D(6) s G(1)
D(7) s CRP(6)*CF(21)
D(8) s CRP(7)*CF(22)
D(9) s CRP(8)*CF(23)
D(10) s G(2)
D(11) s 0.133*G(2)
D(12) s G(4)

```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

```

D(13) s 0.043*G(4)
D(14) s 0.331*G(5)
D(15) s 0.194*G(4)
D(16) s 0.026*G(4)
D(17) s 0.008*G(3)
D(18) s G(3)
D(19) s CRP(9)*CF(24)
D(20) s CRP(10)*CF(25)
D(21) s 0.059*G(3)
D(22) s 0.007*G(1)
D(23) s 0.194*G(2)
D(24) s 0.038*G(4)

```

INFERENCE OF KAPPA(A) FROM MAJOR CONSTITUENTS

```

PAFX s PAK(5) - PAK(4)
GAFX s PAK(5) - PAK(4)
PAOT s PAK(1) - PAK(2)
FPAX s PAK(5) + PAK(4)
PATO s PAK(2) - PAK(1)
PATTO s PAK(3) - PAK(1)
CALL ONEPI(PAFX)
CALL ONEPI(PAOT)
IF(ABS(GAFX).LT.180.0) GO TO 6781
IF(GAFX)6779'6781'6780
6779 FPAX s FPAX + 360.0
GO TO 6781
6780 FPAX s FPAX - 360.0
6781 CALL ONEPI(PATO)
CALL ONEPI(PATTO)
W(1) s PAK(5) + 0.5*PAFX
W(2) s PAK(5)
W(3) s PAK(3)
W(4) s 2.0*PAK(1) - PAK(2)
W(5) s 0.5*FPAX
W(6) s PAK(1)
W(7) s CHSIP(6) + COVU(21)
W(8) s CHSIP(7) + COVU(22)
W(9) s CHSIP(8) + COVU(23)
W(10) s PAK(2)
W(11) s 2.0*PAK(2) - PAK(1)
W(12) s PAK(4)
W(13) s 2.0*PAK(5) - PAK(4)
W(14) s PAK(5)
W(15) s PAK(5) - 1.5*PAFX
W(16) s PAK(5) - 2.0*PAFX
W(17) s PAK(3)
W(18) s PAK(3)
W(19) s CHSIP(9) + COVU(24)
W(20) s CHSIP(10) + COVU(25)
W(21) s PAK(3)
W(22) s PAK(3) - 0.536*PATTO
W(23) s PAK(1) - 0.866*PAOT
W(24) s PAK(5) - 1.43*PAFX
CALL TWOPI(W'24)

```

STATION IDENTIFICATION PRINTED

```

PRINT 13
PRINT 810' (IDENS(KJ)'KJ s 1'18)

```

ZETA PRIME AND R PRIME OUTPUT FOR FIVE MAJOR TIDAL CONSTITUENTS  
AND SECOND'THIRD' AND FOURTH HARMONICS

```

PRINT 811
PRINT 73' (CHSIP(I)'I s 1' 5)
PRINT 812'(CRP(I)'I s 1' 5)
PRINT 813
PRINT 73' (CHSIP(I)'I s 6'10)
PRINT 812'(CRP(I)'I s 6'10)

```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

```
PRINT 5
PRINT 6' CKKF'CRA'CQA'AHNAT
```

EQUILIBRIUM ARGUMENTS AND NODE FACTORS PRINTED

```
PRINT 7
PRINT 811
PRINT 814'(COVU(I))'I s 1' 5)
PRINT 815'(CF(I))'I s 1' 5)
PRINT 816
PRINT 814'(COVU(I))'I s 6'10)
PRINT 815'(CF(I))'I s 6'10)
PRINT 817
PRINT 814'(COVU(I))'I s11'15)
PRINT 815'(CF(I))'I s11'15)
PRINT 818
PRINT 814'(COVU(I))'I s16'20)
PRINT 815'(CF(I))'I s16'20)
PRINT 813
PRINT 814'(COVU(I))'I s21'25)
PRINT 815'(CF(I))'I s21'25)
```

KAPPA' ZETA' AND R PRINTED FOR TIDAL CONSTITUENTS AND HARMONICS  
PRIOR TO ELIMINATION PROCESS

```
PRINT 9
PRINT 811
PRINT 819'(CKAP(I))'I s 1' 5)
PRINT 820'(CHSI(I))'I s 1' 5)
PRINT 821'(CR(I))'I s 1' 5)
PRINT 816
PRINT 819'(CKAP(I))'I s 6'10)
PRINT 820'(CHSI(I))'I s 6'10)
PRINT 821'(CR(I))'I s 6'10)
PRINT 817
PRINT 819'(CKAP(I))'I s11'15)
PRINT 820'(CHSI(I))'I s11'15)
PRINT 821'(CR(I))'I s11'15)
PRINT 818
PRINT 819'(CKAP(I))'I s16'20)
PRINT 820'(CHSI(I))'I s16'20)
PRINT 821'(CR(I))'I s16'20)
```

R' ZETA' KAPPA' AND H PRINTED FOR FIVE MAJOR TIDAL CONSTITUENTS  
AFTER ELIMINATION PROCESS

```
PRINT 11
PRINT 822' CRC(1)'ZETA(1)'PAK(1)'G(1)
PRINT 823' CRC(2)'ZETA(2)'PAK(2)'G(2)
PRINT 824' CRC(3)'ZETA(3)'PAK(3)'G(3)
PRINT 825' CRC(4)'ZETA(4)'PAK(4)'G(4)
PRINT 826' CRC(5)'ZETA(5)'PAK(5)'G(5)
```

COMPUTED VALUES OF H(A) AND KAPPA(A) PRINTED FOR THE CONSTITUENTS

M2	S2	N2	O1	K1
M4	M6	M8	S4	S6

INFERRED VALUES OF H(A) AND KAPPA(A) PRINTED FOR THE CONSTITUENTS

K2	L2	2N	R2	T2	LAMPDA	MU2	NU2
J1	M1	001	P1	Q1	2Q1	PH01	

```
PRINT 15
PRINT 16
PRINT 71'(W(I))'I s 1'5)
PRINT 72'(D(I))'I s 1'5)
PRINT 17
PRINT 71'(W(I))'I s 6'10)
PRINT 72'(D(I))'I s 6'10)
```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

```

PRINT 18
PRINT 71'(W(I))'I s 11'15)
PRINT 72'(D(I))'I s 11'15)
PRINT 19
PRINT 71'(W(I))'I s 16'20)
PRINT 72'(D(I))'I s 16'20)
PRINT 220
PRINT 71'(W(I))'I s 21'24)
PRINT 7360
PRINT 72'(D(I))'I s 21'24)
CALL XMEAN(XTEMP,SUTZ,N)
IF(NECOM.EQ.3.AND.K.EQ.1) GO TO 5998
IF(NECOM.EQ.4.AND.K.EQ.1) GO TO 5998
GO TO 5899
5998 K s 2
GO TO (5899'5899'8355'8355)'NECOM
5999 AZI s 90.0
GO TO 8355
5899 GO TO (1111'1112'1111'1112'1111)'MAP
1112 REWIND 9
1111 CONTINUE
STOP

5 FORMAT(// 28X'7HJ/F(K2)' 6X'2HRA' 8X' 2HQA' 6X' 6HHhO(1))
6 FORMAT(1H '25X' F9.4' 2F10.5' F10.4//)
7 FORMAT(21X'49HEQUILIBRIUM (V + U) AND ELIMINATION (F) ARGUMENTS //)
9 FORMAT(/ 42X'22H ANALYSIS AND INFERENCE //)
11 FORMAT(1H0'3X'33H ELIMINATION OF COMPONENT EFFECTS //15X'4HR(A)'5X'
14HZETA'5X' 5HKAPPA' 5X' 4HH(A) )
13 FORMAT(1H1'48X'27HHARMONIC ANALYSIS' 29-DAYS )
14 FORMAT(1H1'40X'27HHARMONIC ANALYSIS' 15-DAYS' 2X'13HN(2) INFERRED)
15 FORMAT(/// 14X'19HHARMONIC CONSTANTS'1X'13H(H) AND KAPPA //)
16 FORMAT(16X'4HJ(1)'6X'4HK(1)'6X'4HK(2)'6X'4HL(2)'6X'4HM(1))
17 FORMAT(16X'4HM(2)'6X'4HM(4)'6X'4HM(6)'6X'4HM(8)'6X'4HN(2))
18 FORMAT(16X'4H(2N)'6X'4HO(1)'6X'4H(00)'6X'4HP(1)'6X'4HO(1))
19 FORMAT(16X'4H(2Q)'6X'4HR(2)'6X'4HS(2)'6X'4HS(4)'6X'4HS(6))
220 FORMAT(16X'4HT(2)'4X'6HLAMBDA'5X'5HNU(2)'4X'6HRHO(1))
71 FORMAT( 5X' 5HKAPPA' 5F10.2 //)
72 FORMAT( 6X' 4HH(A)' 5F10.4 //)
73 FORMAT( 9X'11HZETA(PRIME)' 5F12.3)
74 FORMAT(24F3.1)
76 FORMAT(F5.0'5I5'F5.0'2I5'F10.8'F5.0)
77 FORMAT(6CX'F3.0'24X'F4.2)
78 FORMAT(24F3.2)
79 FORMAT(24F3.0)
221 FORMAT(I5)
222 FORMAT(3I5)
555 FORMAT(I5'F10.0'F10.2)
808 FORMAT(9A8'9A8)
810 FORMAT(/24X'9A8//24X'9A8//)
811 FORMAT(27X'4HM(2)'8X'4HN(2)'8X'4HS(2)'8X'4HO(1)'8X'4HK(1))
812 FORMAT(1H0'10X'8HR(PRIME)' 5F12.3//)
813 FORMAT(27X'4HM(4)'8X'4HM(6)'8X'4HM(8)'8X'4HS(4)'8X'4HS(6))
814 FORMAT( 12X'7H(V + U)'1X' 5F12.3)
815 FORMAT(1H0'13X' 4HF(A)'2X' 5F12.5 //)
816 FORMAT(27X'4HK(2)'8X'4HL(2)'8X'4H(2N)'8X'4HR(2)'8X'4HT(2))
817 FORMAT(26X'6HLAMBDA'6X'5HMU(2)'7X'5HNU(2)'8X'4HJ(1)'8X'4HM(1))
818 FORMAT(26X'5HOO(1)'8X'4HP(1)'8X'4HO(1)'8X'4H(2Q)'7X'6HRHO(1))
819 FORMAT(15X'5HKAPPA' 5F12.3)
820 FORMAT(1H0'15X' 4HZETA' 5F12.1)
821 FORMAT(1H0'15X' 4HR(A)' 5F12.4 //)
822 FORMAT( 5X' 4HM(2)' F10.5' 2F10.2' F10.5)
823 FORMAT( 5X' 4HN(2)' F10.5' 2F10.2' F10.5)
824 FORMAT( 5X' 4HS(2)' F10.5' 2F10.2' F10.5)
825 FORMAT( 5X' 4HO(1)' F10.5' 2F10.2' F10.5)
826 FORMAT( 5X' 4HK(1)' F10.5' 2F10.2' F10.5)
2037 FORMAT(5F7.3'F5.0)
2038 FORMAT( F5.0'15'F5.0'F5.2'2F6.2)
2039 FORMAT(4A8' 3A8)
4040 FORMAT(1H0'10X' F6.0' 6F10.2)
4041 FORMAT(1H0' 4F10.5)
4440 FORMAT(1H0' 10F12.4 /// 1X' 10F12.4)
7358 FORMAT(1H0'23HJOB TERMINATED.....'24H NSPH OR TFAC s 0 (ZERO))
7359 FORMAT(5X' F10.1'4X' F10.1'4X' 2F10.1)
7360 FORMAT(1H0)
END

```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

SUBROUTINE FORAN(SER' SP' RES' ZEP' N' M )

FOURIER ANALYSIS - DETERMINE ZETA(PRIME)AND P(PRIME)

```

DIMENSION SER(N)' RES(M)' ZEP(M)
DO 55 JR s 1' M
RES(JR) s 0.0
ZEP(JR) s 0.0
C s 0.0
S s 0.0
DO 10 L s 1'N
C s C COS(FLOAT(L-1)*(3.141593*(FLOAT(JR) *SP)))*SER(L)
100 S s S SIN(FLOAT(L-1)*(3.141593*(FLOAT(JR) *SP)))*SFR(L)
C s 2.0/ FLOAT(N)* C
S s 2.0/ FLOAT(N)* S
X s S/C
IF DIVIDE CHECK 14'15
14 IF(S)16'55'17
16 ZEP(JR)s 270.0
GO TO 18
17 ZEP(JR) s 90.0
GO TO 18
15 ZEP(JR) s ATAN(X)*57.29578
IF(S) 32'32'34
32 IF(C) 33'55'37
33 ZEP(JR) s 180.0 + ZEP(JR)
GO TO 18
34 IF(C) 35'17'36
35 ZEP(JR) s ZEP(JR) + 180.0
GO TO 18
37 ZEP(JR) s ZEP(JR) + 360.0
GO TO 18
36 ZEP(JR) s ZEP(JR)*1.0
18 RES(JR) s SORT( C**2 + S**2)
55 CONTINUE
RETURN
END

```

SUBROUTINE SASTP(DEG C5F'CKKF'ACS'APS'ACK'APK'IOT'TAB1'TAB2'TAB3'  
1TAB4'TAB5'TAB6'SL'VPP'PS'VP'CF'JOP)

DETERMINE SECONDARY CONSTITUENT EFFECTS

```

DIMENSION DEG(IOT)'TAB1(IOT)'TAB2(IOT)'TAB3(IOT)'TAB4(IOT)'TAB5(IOT)
1TAB6(IOT)'CF(JOP)
2043 FORMAT( 1H0'4F10.5 ///)
2044 FORMAT(///// 6X'4HSMAC'6X'4HPROD'6X'4HACCP'4X'5HPRESAM)
2045 FORMAT(///// 2X' 6F10.4)
AMT s SL - 0.5*VPP
CALL TWOPI(AMT' 1)
CALL TERPO(DEG'TAB3'37'RAK'AMT)
TAZ s RAK
AMP s SL - PS
CALL TWOPI(AMP'1)
CALL TERPO(DEG'TAB5'37'RAL'AMR)
TAZ1 s RAL
ACS s RAK*CKKF + RAL
CALL TERPO(DEG'TAB4'37'SK0'AMT )
TAZ2 s SK0
CALL TERPO(DEG'TAB6'37'STOX'AMR)
TAZ3 s STOX
APS s STOX*(1.0 + (SK0*CKKF))
FALT s SL - 0.5*VP
CALL TWOPI(FALT'1)
CALL TERPO(DEG'TAB1'37'PKX'FALT)
TAZ4 s PKX
ACK s PKX*C5F
CALL TERPO(DEG'TAB2'37'PKXA'FALT)
TAZ5 s PKXA
APK s 1.0 + (C5F*PKXA)
PRINT 2044
PRINT 2043' ACS'APS'ACK'APK
PRINT 2045'TAZ' TAZ1' TAZ2' TAZ3' TAZ4' TAZ5
RETURN
END

```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

SUBROUTINE DAYXX(MONTH'DAY'STT'TM'DAYB'DAYM'GRBS'GRMS'CP)

```

8800 FORMAT( /// 5X' 8H DAYB s 'F5.0'10X' 8H DAYM s 'F5.0 /// 5X' 8H G
1HBS s 'F7.2'10X' 8H GHMS s 'F7.2 /// 5X'17H ORIGINAL T.M. s 'F7.2'
210X'18H CORRECTED T.M. s 'F7.2)
GO TO (207'209'211'213'215'217'219'251'223'225'227'229)'MONTH
207 DAYB s DAY 207
GO TO 230 208
209 DAYB s DAY + 31. 209
GO TO 230 210
211 DAYB s DAY + 59. 211
GO TO 230 212
213 DAYB s DAY + 90. 213
GO TO 230 214
215 DAYB s DAY + 120. 215
GO TO 230 216
217 DAYB s DAY + 151. 217
GO TO 230 218
219 DAYB s DAY + 181. 219
GO TO 230
251 DAYB s DAY + 212. 221
GO TO 230 222
223 DAYB s DAY + 243. 223
GO TO 230 224
225 DAYB s DAY + 273. 225
GO TO 230 226
227 DAYB s DAY + 304. 227
GO TO 230 228
229 DAYB s DAY + 334.
230 IF(STT.GT.12.0) GO TO 233 230
CP s TM + (STT*15.0)
IF(CP.LE.180.0) GO TO 235
233 CP s TM - (24.00 - STT)*15.0 233
DAYB s DAYB + 1. 234
235 GRBS s CP/15.0 235
GRMS s GRBS + 12.00 236
IF(GRMS.GT.24.0) GO TO 240 237
DAYM s DAYB + 14.0
GO TO 242 239
240 GRMS s GRMS - 24.00
DAYM s DAYB + 16.0
242 PRINT 8800'DAYB'DAYM'GRBS'GRMS'TM'CP
RETURN
END

```

SUBROUTINE AZIM(DX'VR'A'VN'K'J'COMPV'NEC)

COMPUTE MAJOR OR MINOR AXIS OR COMPUTE NORTH AND EAST COMPONENTS

```

DIMENSION DX(J)' VR(J)' VN(J)
DO 10 I s 1'J
100 VN(I) s (DX(I) + COMPV - A )*0.0174533
GO TO (1'2)'K
1 DO 66 I s 1'J
66 VN(I) s VR(I)*COS(VN(I))
GO TO 88
2 IF(NEC.EQ.4.OR.NEC.EQ.3) GO TO 109
DO 77 I s 1'J
77 VN(I) s VR(I)*SIN(VN(I))
RETURN
88 DO 99 LM s 1'J
TB s VN(LM)
TA s VR(LM)
99 VN(LM) s SIGN(TA'TB)
109 RETURN
END

```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

SUBROUTINE ASTRO(XYER'DAYB'DAYM'GRBS'GRMS'JOBX)

DETERMINATION OF ORBITAL ELEMENTS FOR OBSERVED SERIES

```

COMMON/COSTX/CXX(30)'OEX(5)
COMMON / LEAPYP / DAY*MONTH
2110 FORMAT(1H0' 3RERROR.....PARAMETER (I) EXCEEDS LIMITS )
2111 FORMAT(1H0'15X'1HR'10X'1H0'15X'9HU OF M(2))
2112 FORMAT( 8X' F10.3' 3X' F10.3' 9X' F10.4)
2040 FORMAT(1H1'10F10.3//// 1X'10F10.3//// 1X'10F10.3)
CALL ORBIT(XCFN'XSX'XPX'XHX'XP1X'XNX'OEX'IT'XYER'5)
DO 30 NOE s 1'30
30 CXX(NOE) s 0.0
   XCET s XCEN + 1.0
   DORY s 0.25*(XYER - XCET)
   AMI s XYER - XCEN
   AMIT s AINT(DORY)
   FARM s 0.25*(AMI)
   FAPX s FARM - AINT(FARM)
   IF(FAPX.EQ.0.0.AND.MONTH.EQ.2) GO TO 35
31 IF(FAPX.EQ.0.0.AND.DAYB.LE.60.0) DAYB s DAYB - 1.0
   IF(FAPX.GT.0.0) DAYB s DAYB - 1.0
   IF(FAPX.EQ.0.0.AND.DAYM.LE.60.0) DAYM s DAYM - 1.0
   IF(FAPX.GT.0.0) DAYM s DAYM - 1.0
32 CXX(1) s XSX + 129.38482032*AMI + 13.176396768*(DAYB + AMIT) + 0.5
   149016532*GRBS
   CXX(2) s XPX + 40.66246584*AMI + 0.111404016*(DAYB + AMIT) + 0.004
   1641834*GRBS
   CXX(3) s XHX - 0.238724988*AMI + 0.9856473288*(DAYB + AMIT) + 0.04
   110686387*GRBS
   CXX(4) s XP1X + 0.01717836*AMI + 0.000047064*(DAYB + AMIT) + 0.000
   1001961*GRBS
   CXX(5) s XPX + 40.66246584*AMI + 0.111404016*(DAYM + AMIT) + 0.004
   1641834*GRMS
   CXX(6) s XNX - 19.328185764*AMI - 0.0529539336*(DAYM + AMIT) - 0.0
   1022064139*GRMS
   IF(JOBX.LE.15.AND.JOBX.GT. 0 ) GO TO 40
   CALL TWOPI(CXX'6)
   GO TO 41
35 IF(DAY.EQ.1.) GO TO 32
   GO TO 31
40 CXX(7) s XPX + 40.66246584*AMI + 0.111404016*(DAYM + AMIT) + 0.004
   1641834*GRBS
   CXX(8) s XNX - 19.328185764*AMI - 0.0529539336*(DAYM + AMIT) - 0.0
   1022064139*GRBS
   CALL TWOPI(CXX' 8)
41 AN s CXX(6)*0.0174533
   AX s CXX(6)
   EYF s .9136949 - 0.0356926*COS(AN)
   CXX(9) s ACOS(EYF)*57.2957795
   IF(CXX(9).LT.17.0.OR.CXX(9).GT.30.0) PRINT 2110
   CIG s CXX(9)*0.0174533
   IF(CIG.EQ.0.0) GO TO 230
   IF(AX.EQ.0.0.OR.AX.EQ.180.0) GO TO 230
   VXX s .0896831*SIN(AN)/SIN(CIG)
   CXX(10) s ASIN(VXX)*57.2957795
   IF(AX.GT.180.0.AND. CXX(10).GT.0.0) CXX(10) s -1.0*CXX(10)
   CVX s CXX(10)*0.0174533
   EXX s .2067274*SIN(AN)*(1.0 - 0.0194926*COS(AN))
   IF(EXX.EQ.0.0) GO TO 202
   EZZ s .9979852 + 0.2067274*COS(AN) - 0.0020148*COS(2.0*AN)
   IF(EZZ.EQ.0.0) GO TO 202
   FEXZ s EXX/EZZ
   IF(FEXZ.GT.3450.0) GO TO 202
   CXX(11) s ATAN(FEXZ)*57.2957795
   IF(AX.GT.180.0.AND.CXX(11).GT.0.0) CXX(11) s -1.0*CXX(11)
   CFY s CXX(11)*0.0174533
202 VPX s SIN(CVX)/(COS(CVX) + 0.334766/SIN(2.0*CIG))
   CXX(12) s ATAN(VPX)*57.2957795
   IF(AX.GT.180.0.AND.CXX(12).GT.0.0) CXX(12) s -1.0*CXX(12)
   PVC s CXX(12)*0.0174533
   VPY s SIN(2.0*CVX)/(COS(2.0*CVX) + 0.0726184/SIN(CIG)**2)
   CXX(13) s ATAN(VPY)*57.2957795
   IF(AX.GT.180.0.AND.CXX(13).GT.0.0) CXX(13) s -1.0*CXX(13)
   PVCP s CXX(13)*0.0174533

```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

```

220 PGX s CXX(5) - CXX(11)
    CALL TWOPI(PGX' 1)
    XPG s PGX*0.0174533
    CXX(14) s PGX
    RAX s SIN(2.0*XPG)/(COS(0.5*CIG)**2/(6.0*SIN(0.5*CIG)**2) - COS(2.
10*XPG))
    RXX s ATAN(RAX)*57.2957795
    UM2 s 2.0*(CXX(11) - CXX(10))
    UL2 s UM2 - RXX
    IF(UL2.GT.180.0) UL2 s UL2 - 180.0
    IF(UL2.LT.180.0) UL2 s UL2 + 180.0
    CXX(15) s UL2
    ZFS s ( 5.0*COS(CIG) - 1.0)*SIN(XPG)
    ZFC s ( 7.0*COS(CIG) + 1.0)*COS(XPG)
    CALL FITAN(ZFS'ZFC'QXX'2)
    CRAV s 0.5*( UM2 ) + QXX + 90.0
    CALL TWOPI(CRAV'1)
    CXX(16) s CRAV
    IF(JORX.GT.15.AND.JORX.GT.0 ) GO TO 88
    PGXX s CXX(7) - CXX(11)
    CALL TWOPI(PGXX'1)
    XXPG s PGXX*0.0174533
    CXX(17) s PGXX
    BATX s CXX(8)*0.0174533
    FYFX s 0.9136949 - 0.0356926*COS(BATX)
    CXX(2 ) s ACOS(FYFX)*57.2957795
    UM2X s 2.0*(CXX(11) - CXX(10))
    FYIT s CXX(20)*0.0174533
    ZFXS s (5.0*COS(FYIT) - 1.0)*SIN(XXPG)
    ZFXC s ( 7.0*COS(FYIT) + 1.0)*COS(XXPG)
    CALL FITAN( ZFXS'ZFXC'QXXX'2)
    CXX(19) s 0.5*(UM2X) + QXXX + 90.0
    CRAVX s CXX(19)
    CALL TWOPI(CRAVX'1)
    CXX(19) s CRAVX
88 DO 33 NT s 1'30
    DROP s CXX(NT)*10000. + 5.0
33 CXX(NT) s AINT(DROP)*0.0001
    PRINT 2040'(CXX(1AX)'1AX s 1'30)
    PRINT 2111
    PRINT 2112' RXX'QXX'UM2
    RETURN
END

```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

SUBROUTINE ORBIT(XCEN'XSX'XPX'XHX'XP1X'XNX'OEX'T'XYER'NNN)

DETERMINATION OF ORBITAL FLEMENTS FOR BEGINNING OF CENTURY

```

    DIMENSION OEX(NNN)
  8  FORMAT(1H0' 5F12.4' 5X' F5.0' 2F6.1)
    S s 13.1763968
    P s 0.1114040
    XH s .9856473
    P1 s .0000471
    XN s .0529539
    XCEN s XYER*0.01 + 0.001
    XCEN s AINT(XCEN)*100.0
    T s -3.0
    YR s 2.5
    GAT s 1600.0
    DO 10 JX s 1'30
    GP s (GAT)*0.01/4.0 + 0.00001
    FPX s APS(GP)
    FP s AINT(FPX)
    COL s FPX - FP
    IF(COL.LT.0.010) GO TO 11
    IF(GAT.EQ.XCEN) GO TO 12
    YR s YR - 1.0
    GO TO 9
  11 IF( GAT.EQ.XCEN) GO TO 12
    9  GAT s GAT + 100.0
  10  CONTINUE
  12  T s (GAT - 1900.0)*0.01
    OEX(1) s 270.43742222 + 307.892*T + 0.002525*T**2 + 0.00000189*T**
    13 + YR*S
    OEX(2) s 334.32801944 + 109.0322055*T - 0.01034444*T**2 - 0.000012
    15*T**3 + YR*P
    OEX(3) s 279.69667778 + 0.768925*T + 0.0003025*T**2 + YR*XH
    OEX(4) s 281.22083333 + 1.719175*T + 0.00045278*T**2 + 0.00000333*
    1T**3 YR*P1
    OEX(5) s 259.18253333 - 134.1423972*T + 0.00210556*T**2 + 0.000002
    122*T**3 + YR*XN
    CALL TWOPI(OEX'5)
    XSX s OEX(1)
    XPX s OEX(2)
    XHX s OEX(3)
    XP1X s OEX(4)
    XNX s OEX(5)
    PRINT 8' (OEX(JX)'JX s 1'5) ' GAT' T' YR
    RETURN
  END

```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

```

      SUBROUTINE TWOPI( AUG' IO)
C
C
C      ELIMINATE NEGATIVE OR ANGLES GREATER THAN 360 DEGREES
C
      DIMENSION AUG(10)
      DO 114 MO s 1'10
120 IF(AUG(MO))112'114'113
112 AUG(MO) s AUG(MO)+ 360.0
      GO TO 120
113 IF(AUG(MO) - 360.0)114'114'115
115 AUG(MO) s AUG(MO) - 360.0
      GO TO 120
114 CONTINUE
      RETURN
      END
      SUBROUTINE FITAN( AUS'AUC'RTA'JMAP)
C
C
C      DETERMINE ARCTANGENT AND PLACE IN CORRECT QUADRANT
C
      BXG s AUS/AUC
      IF DIVIDE CHECK 14'15
14 IF(AUS)16'55'17
16 RTA s 270.0
      GO TO 88
17 RTA s 90.0
      GO TO 88
15 RTA s ATAN(BXG)*57.2957795
      GO TO (88'38)'JMAP
38 IF(AUS)32'32'34
32 IF(AUC)33'55'37
33 RTA s 180.0 + RTA
      GO TO 88
34 IF(AUC)35'17'88
35 RTA s RTA + 180.0
      GO TO 88
37 RTA s RTA + 360.0
      GO TO 88
55 RTA s .0
88 CONTINUE
      RETURN
      END
      SUPROUTINE XMEAN(VIN'FH'N)
C
C
C      MEAN SERIES FOR NON-TIDAL CURRENT OR MEAN SEA LEVEL
C
      DIMENSION VIN(N)
15 FORMAT(//// 1X'14H SUM OF SERIES'3X'F12.3 // 1X' 7HDIVISOR'12X'I10
1 // 1X'14HMEAN OF SERIES'5X'F10.5 // 1X'10HTOTAL DATA'9X'I10 )
      MA s N
      EH s .0
      DO 10 NA s 1'N
      IF(VIN(NA).EQ.0.0) MA s MA - 1
10 FH s EH + VIN(NA)
      BH s FH/FLOAT(MA)
      PRINT 15' EH' MA' BH' N
      RETURN
      END

```

h  
h

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

SUBROUTINE TERPO(ANG,TXX,LID,ANSWER,AUGM)

INTERPOLATE TABLES 21'22'23'24'25'AND 26

```

DIMENSION ANG(LID), TXX(LID)
1  FORMAT(///23H JOB TERMINATED.....26HFAILED TO INTERPOLATE ANG.)
   LIM = LID - 1
   DO 20 ION = 1,LIM
     IF(AUGM.GT.ANG(ION).AND.AUGM.LT.ANG(ION+1)) GO TO 28
     IF(AUGM.EQ.ANG(ION)) GO TO 26
     IF(AUGM.EQ.ANG(ION+1)) GO TO 27
     GO TO 200
26  ANSWER = TXX(ION)
     GO TO 201
27  ANSWER = TXX(ION+1)
     GO TO 201
28  REW = AUGM*0.1
     WER = REW - AINT(REW)
     FRA = WER*10.0
     RET = ABS(TXX(ION))
     TFX = ABS(TXX(ION+1))
     IF(RET.GT.TFX) GO TO 29
     IF(RET.LT.TFX) GO TO 30
     IF(RET.EQ.TFX) GO TO 31
29  DIFR = (RET - TFX)*0.1
     IF(TXX(ION).GE.0.0.AND.TXX(ION+1).LT.0.0) DIFR = (RET + TFX)*0.1
     IF(TXX(ION).LT.0.0.AND.TXX(ION+1).GE.0.0) DIFR = (RET + TFX)*0.1
     DIFX = DIFR*FRA
     CHS = SIGN(DIFX,TXX(ION))
     ANSWER = TXX(ION) - CHS
     GO TO 201
30  DIFR = (TEX - RET)*0.1
     IF(TXX(ION).GE.0.0.AND.TXX(ION+1).LT.0.0) DIFR = (RET + TFX)*0.1
     IF(TXX(ION).LT.0.0.AND.TXX(ION+1).GE.0.0) DIFR = (RET + TFX)*0.1
     DIFX = DIFR*FRA
     CHS = SIGN(DIFX,TXX(ION+1))
     ANSWER = TXX(ION) + CHS
     GO TO 201
31  IF(TXX(ION).GF.0.0.AND.TXX(ION+1).GF.0.0) GO TO 26
     IF(TXX(ION).LT.0.0.AND.TXX(ION+1).LT.0.0) GO TO 26
     IF(TXX(ION).GF.0.0.AND.TXX(ION+1).LT.0.0) GO TO 32
     IF(TXX(ION).LT.0.0.AND.TXX(ION+1).GF.0.0) GO TO 32
     PRINT 1
     CALL EXIT
32  DIFR = (TXX(ION+1) - TXX(ION))*0.1
     DIFX = DIFR*FRA
     ANSWER = TXX(ION) + DIFX
     GO TO 201
200 CONTINUE
201 RETURN
     END

```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

SUBROUTINE DETAZ(FIN'AZO'NR'COMPV'VIN'XTEMP'INC)

DETERMINATION OF TRUE AZIMUTH  
THIS ROUTINE IS A SPECIAL PURPOSE PROGRAM FOR USE WITH TIDAL CURRENT  
ANALYSES IN THE COAST AND GEODETIC SURVEY

```

    DIMENSION FIN(NR)'VIN(NR)'XTEMP(NR)
2  FORMAT(1H1'30H AZIMUTH OR MEAN FLOOD DIR. s 'F7.2'5X'I5'5X'F10.2)
3  FORMAT(1H0'14HERROR IN DETAZ)
6  FORMAT(1H1'28HOPERATOR.....STOP THIS JOB)

    LMN s
    SUMD s 0.0
    AIZ s AZO
    IF(AZO.EQ.360.0) AIZ s 0.0
    DO 10 KAZ s 1'NR
    TDIR s FIN(KAZ) + COMPV
    IF(TDIR.LE.20.0) TDIR s TDIR + 360.0
    IF(ABS(TDIR - AIZ - 360.0).LE. 20.0) GO TO 90
    IF(ABS(TDIR - AZO).LE. 20.0) GO TO 90
    IF(ABS(TDIR - AZO + 360.0).LE. 20.0) GO TO 90
    GO TO 100
90  LMN s LMN + 1
    SUMD s SUMD + TDIR
100 CONTINUE
    AZO s SUMD / FLOAT(LMN)
    IF DIVIDE CHECK 8'5
8  PRINT 6
4  PRINT 3
    RETURN
5  AZO s AINT(AZO)
    CALL TWOPI(AZO'1)
    PRINT 2' AZO'LMN'SUMD
    IF(INC.EQ.00) GO TO 7
    CALL TILT(VIN'XTEMP'NR)
7  RETURN
    END

```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

```
SUBROUTINE EDAT(MX'VIN'DIN'MA'LX'ICOR'CD'CV'LRD'XTEMP'INC)
```

```
INFER DATA CORRECTIONS TO SERIES FROM MAGNETIC TAPE
```

```

DIMENSION ICOR(LX)' DIN(MA)'VIN(MA)'CD(LX)'CV(LX)'XTEMP(MA)
COMMON/FORT/AQ(4)'BQ(3)
5  FORMAT(19X'A5)
6  FORMAT(60X'F3.0'24X'F4.2)
7  FORMAT(5X'I5'5X'F5.0'5X'F5.2'5X'I5'5X'A5)
9  FORMAT(24F3.2)
10 FORMAT(24F3.0)
12 FORMAT(110X'F3.0)
51 FORMAT(19X'F5.0)
REWIND 9
IF(INC.EQ.00) GO TO 14
IF(LRD.EQ.00) GO TO 13
READ(9'51)(XTEMP(IM)'IM s 1'LRD)
13 READ(9'BQ) (XTEMP(IP)'IP s 1'MA)
REWIND 9
14 IF s 1
LAG s
LEN s 1
DO 98 I s 1'MX'LEN
IF(LRD)99'1'2
2 IF(I LRD)3'3'1
3 READ(9'5) ITRASH
GO TO 98
1 LAG s LAG + 1
IF(IF.GT.LX) GO TO 11
LD s ICOR(IE)
IF(LD.EQ.1)GO TO 4
LDX s ICOR(IF) - 1
11 IF(IF.GT.LX) LDX s MX
DO 40 IX s 1'LDX
READ(9'AQ) DIN(LAG)' VIN(LAG)
IF(IX.EQ.LDX) GO TO 400
LAG s LAG + 1
400 CONTINUE
IF(LDX.EQ.MX) GO TO 97
LEN s LD - 1
GO TO 98
4 READ(9'5) ITRASH
DIN(LAG) s CD(IF)
VIN(LAG) s CV(IF)
XTEMP(LAG) s 0.0
PRINT 7' I' DIN(LAG)' VIN(LAG)' ICOR(IE)'ITRASH
LEN s 1
IF s IE + 1
98 CONTINUE
97 IF(LAG.LT.MA) GO TO 8
GO TO 99
8 LAG s LAG + 1
READ 9' (VIN(IN) 'IN s LAG'MA)
READ 10' (DIN(ID)' ID s LAG'MA)
DO 30 MAG s LAG'MA
200 XTEMP(MAG) s 0.0
99 IF(INC.EQ.1) CALL TILT(VIN'XTEMP'MA)
IF(INC.EQ.1) INC s 0
RETURN
END

```

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES—Continued

SUBROUTINE TILT(GIN'TEM'LIT)

CORRECT DATA FOR INSTRUMENTAL TILT

```

DIMENSION GIN(LIT)'TEM(LIT)
2  FORMAT(1H0'I6'5X'28HTILT EXCEEDS 35 DEGREE LIMIT'3X'I3)
DO 10 IP s 1'LIT
  IF(TEM(IP).EQ.0.0) GO TO 100
  MIX s IFIX(TEM(IP))
  NIX s MIX/5 + 1
  GO TO (100'101'102'103'104'105'106'107'110'110'110'110)'NIX
101 GIN(IB) s .03*GIN(IB) + GIN(IP)
  GO TO 100
102 GIN(IB) s .06*GIN(IB) + GIN(IP)
  GO TO 100
103 GIN(IB) s .09*GIN(IB) + GIN(IP)
  GO TO 100
104 GIN(IB) s .12*GIN(IB) + GIN(IP)
  GO TO 100
105 GIN(IB) s .16*GIN(IB) + GIN(IP)
  GO TO 100
106 GIN(IB) s .20*GIN(IB) + GIN(IP)
  GO TO 100
107 GIN(IB) s .25*GIN(IB) + GIN(IP)
  GO TO 100
108 GIN(IP) s .51*GIN(IB) + GIN(IP)
  GO TO 100
109 GIN(IB) s .65*GIN(IB) + GIN(IP)
  GO TO 100
110 PRINT 2' IB'MIX
100 CONTINUE
  RETURN
END
SUBROUTINE TFMP(XSER'XTEMP'I )

```

STORE SERIES FOR FOURIER ANALYSIS

```

DIMENSION XSER(I) ' XTFMP(I)
DO 10 J s 1' I
100 XTFMP(J) s XSER(J)
  RETURN
END
SUBROUTINE SORT(SORX'VX'KK'JJ)

```

SORT DATA AND FORM NEW SERIES

```

DIMENSION SORX(KK)' VX(KK)
COMMON/CONT/NN
1  DO 10 I s 1'KK'JJ
  NN s I/JJ + 1
100 VX(NN) s SORX(I)
  RETURN
END
SUBROUTINE ONEPI(AUX)

```

TEST FOR 180 DEGREE DIFFERENCE BETWEEN TWO ANGLES

```

IF(ABS(AUX) -180.0)170'170'163
163 IF(AUX)164'164'165
164 AUX s AUX + 360.0
  GO TO 170
165 AUX s AUX - 360.0
170 RETURN
END

```



*(Continued from inside front cover)*

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